PETROLOGY AND ORIGIN OF THE DAY BOOK DUNITE,
YANCEY COUNTY, NORTH CAROLINA

A Thesis Presented in Partial Fulfillment of the Requirements
for the Degree Bachelor of Science

By

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Approved By:

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ABSTRACT

The Day Book dunite body is one of many "alpine-type" ultramafic bodies that outcrop in the Blue Ridge belt of the southern Appalachians. The petrography of the Day Book dunite was studied in thin sections and polished surfaces to identify primary and secondary minerals, paragenetic relationships, and recrystallization and deformational textures. Olivine, enstatite and chromite comprise the primary mineral assemblage, and the secondary minerals include serpentine, talc, chlorite, anthophyllite, magnesite, tremolite and magnetite. Small, recrystallized olivine grains form a mosaic in which are found large, deformed, relict olivine grains. "Disseminated" chromite occurs as polygonal, straight-sided grains that represent annealing recrystallization, whereas "massive" chromite exhibits cataclastic texture and alteration to magnetite.

The Day Book body formed as upwelled mantle material in a Precambrian rift system along the margin of the North American continent, and it was squeezed and thrust into place during the Taconic orogeny. Lack of contact metamorphism and evidence of chilled borders indicate that the dunite body was emplaced as "cold", solid, mantle-derived ultramafic material that later underwent hydrous alteration during regional metamorphism and/or the intrusion of pegmatites.

ACKNOWLEDGEMENTS

I would like to thank Dr. Douglas Pride for his guidance during the research and writing of this thesis. I also would like to thank Robin Baker, Scott Langford and Mary Dylewski for preparing the thin sections and polished surfaces.

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CHAPTER I

INTRODUCTION

The Day Book dunite body outcrops in the Spruce Pine Synclinorium, within the Blue Ridge belt of the southern Appalachians. It is located about three miles north of Burnsville, Yancey County, North Carolina. Specifically, it lies at about the intersection of State Highway 197 and Mine Fork Creek (Figures 1 & 2) (Kulp and Brobst, 1954).

The Day Book mine has produced olivine intermittently for many years (Wilson et al., 1976). In 1941, the Day Book deposit was the second largest olivine quarry in North Carolina (Hunter, 1941). Hunter estimated that the Day Book deposit contained 3,180,000 tons of relatively unaltered granular olivine, and the deposit has been mined primarily for olivine, although vermiculite also has been produced. Chromite is also present, as disseminated grains and as lenses and pods within the dunite. In general, the chromite content is too low to be of economic value, but some chromite was produced during 1917-1918 (Kulp and Brobst, 1954). It was produced from a 15-inch thick vein located on a hill on the east side of Mine Fork Creek, within the Day Book dunite body. Anthophyllite asbestos is also present in the Day Book deposit, but it does not occur in economic concentrations.

Specifics of the mining history of the Day Book deposit, in particular information on ore tonnages, are not available for the period from 1941 to 1984, but it is evident that the deposit was an important producer of olivine at least until 1976 (Hunter, 1941; Wilson et al.

1976). The I.M.C. Olivine Co. of Green Mountain, North Carolina currently is extracting olivine from the deposit (Figure 3).

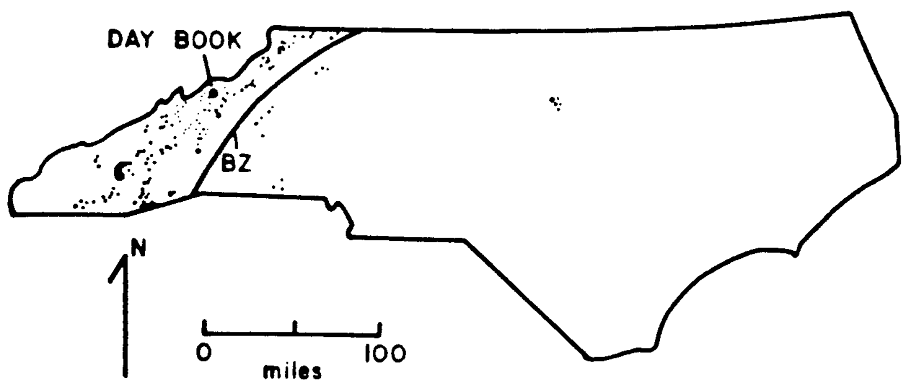

FIGURE 1. Map showing the location of the Day Book dunite (from Swanson, 1981).

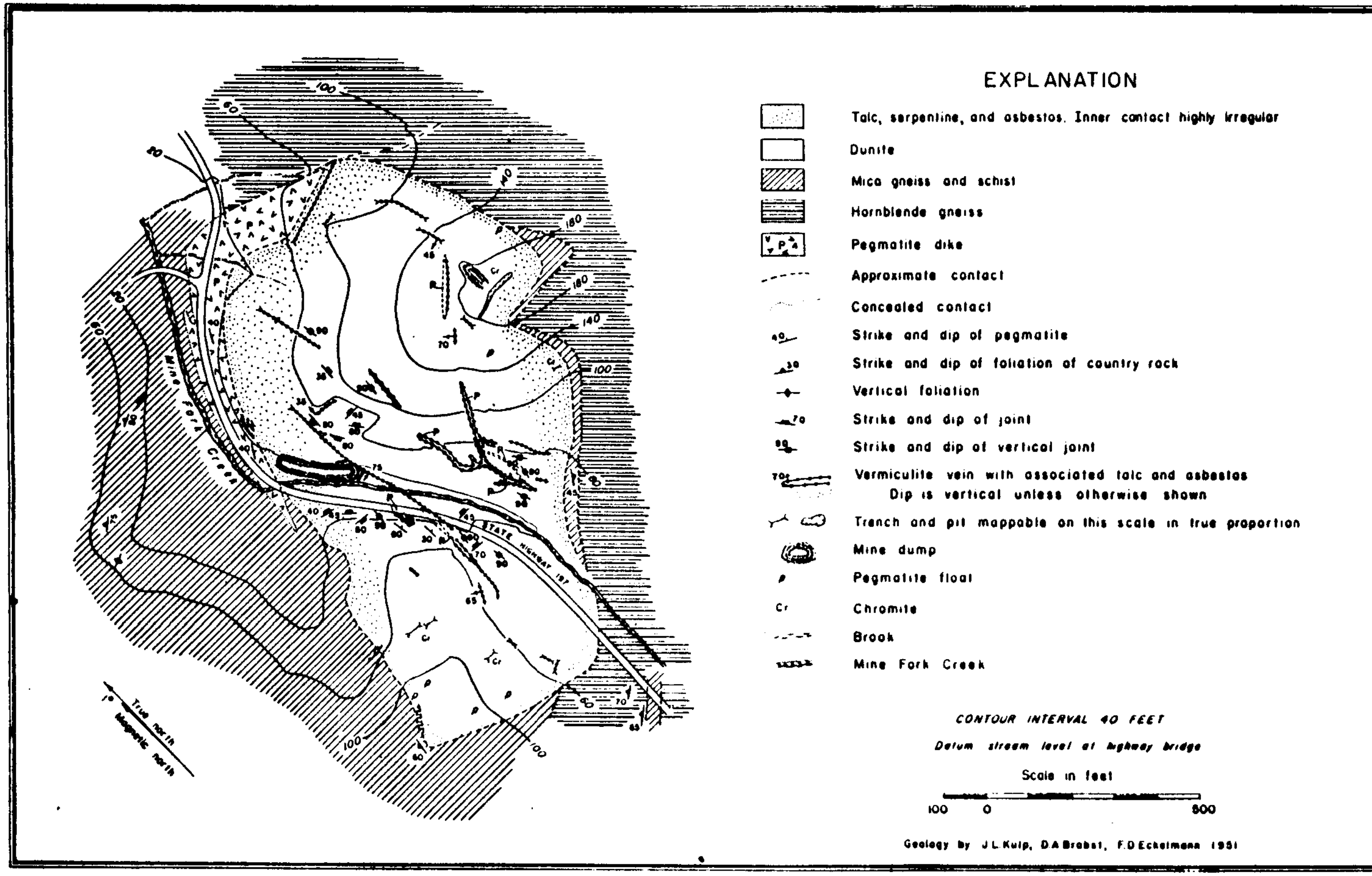

FIGURE 2. Geologic map of the Day Book dunite (from Kulp and Brobst, 1954).

FIGURE 3. Photograph of the mining operation at the Day Book dunite.

CHAPTER II

PURPOSE

The dunite exposed in the Day Book mine is representative of a number of ultramafic bodies that form a well-defined chain in the Blue Ridge belt of the southern Appalachians. Most researchers believe that the ultramafic bodies in the Blue Ridge belt were emplaced about 450-480 m.y. ago, prior to or at the beginning of the Taconic orogeny (Misra and Keller, 1978). The method of emplacement of these "alpine-type" peridotites has been the subject of considerable controversy in recent years. Understanding the origin, method of emplacement, and petrography of these bodies will help in understanding the evolution of the southern Appalachians, particularly with respect to plate tectonism. The goals of this study are:

(1) To describe the petrology of the Day Book dunite, focusing on the description of (a) primary and secondary minerals, and (b) the deformation and recrystallization textures of the primary and secondary minerals.

(2) To review the theories of emplacement proposed for ultramafic bodies in the southern Appalachians, and to evaluate the theories with respect to the geology history of the Day Book dunite.

CHAPTER III

ULTRAMAFIC BODIES IN THE SOUTHERN APPALACHIANS

"Alpine-Type" Peridotites

"Alpine-type" peridotites occur in many of the major orogenic belts of the world. The bodies generally are elongated parallel to regional structures (Ave'lallement et al., 1970). The bodies are small and lens-shaped, exhibit irregular layering and discontinuous bands and "pods" of chromite, plus a high degree of serpentinization (Stanton, 1972). The borders of the bodies are often brecciated and serpentinized and lack evidence of contact metamorphism (Ave'lallement et al., 1970). According to Misra and Keller (1978), the lack of thermal contact metamorphism generally rules out the possibility of in situ crystallization from a peridotitic melt. Thus, the alpine-type bodies are allochthonous, and they are believed to have originated in the upper mantle (Ave'lallement et al., 1970).

Chidester and Cady (1972) divided alpine-type peridotites into two groups. The first are those generated beneath oceanic (simatic) crust, and the second group are those generated beneath continental (sialic) crust. These authors proposed that obducted ophiolites belong to the former, and that intrusive or diapiric bodies belong to the latter.

According to Misra and Keller (1978), the phrase "alpine-type" includes alpine obducted ophiolite suites as well as other ultramafic bodies in orogenic belts. These authors defined two subtypes, according to the geology setting. The first are the ophiolites or ophiolitic bodies that may occur as large, allochthonous sheet-like bodies, and as chaotic blocks in melange terranes. The second subtype includes tectonic or diapiric intrusives that generally are smaller, lenticular bodies, associated with metamorphosed volcanic and sedimentary rocks of eugeosynclinal affiliation. Ophiolite sequences, which represent fragments of oceanic crust, thus far have only been described from the central and northern Appalachians (e.g. Newfoundland). No ophiolite sequences have been found to date in the southern Appalachians (Stevens et al., 1974; Misra and Keller, 1978).

Ultramafic bodies in the southern Appalachians are of the alpine-type. Two "chains" of alpine-type ultramafic bodies can be distinguished in the southern Appalachians. The first is a relatively well-defined, but discontinuous chain of ultramafic bodies that is present within the Blue Ridge from the southern Appalachians to Newfoundland. Several hundred small bodies have been identified in the Blue Ridge belt of North Carolina and Georgia (Figure 4) (Misra and Keller, 1978). The bodies generally lie within Precambrian metasedimentary-metavolcanic sequences.

A less distinct chain of ultramafic bodies lies in the Piedmont province. In contrast to the Blue Ridge belt, the ultramafic bodies in the Piedmont province occur as small, isolated bodies, irregularly scattered throughout the belt (Figure 4) (Misra and Keller, 1978). The ultramafic bodies in the Piedmont belt are believed to have been emplaced as diapirs, rising above a subduction zone (Steven et al., 1974; Misra and Keller, 1978).

Origin and Emplacement of Ultramafic Bodies in the Blue Ridge Belt

Most investigators agree that the source of the ultramafic material

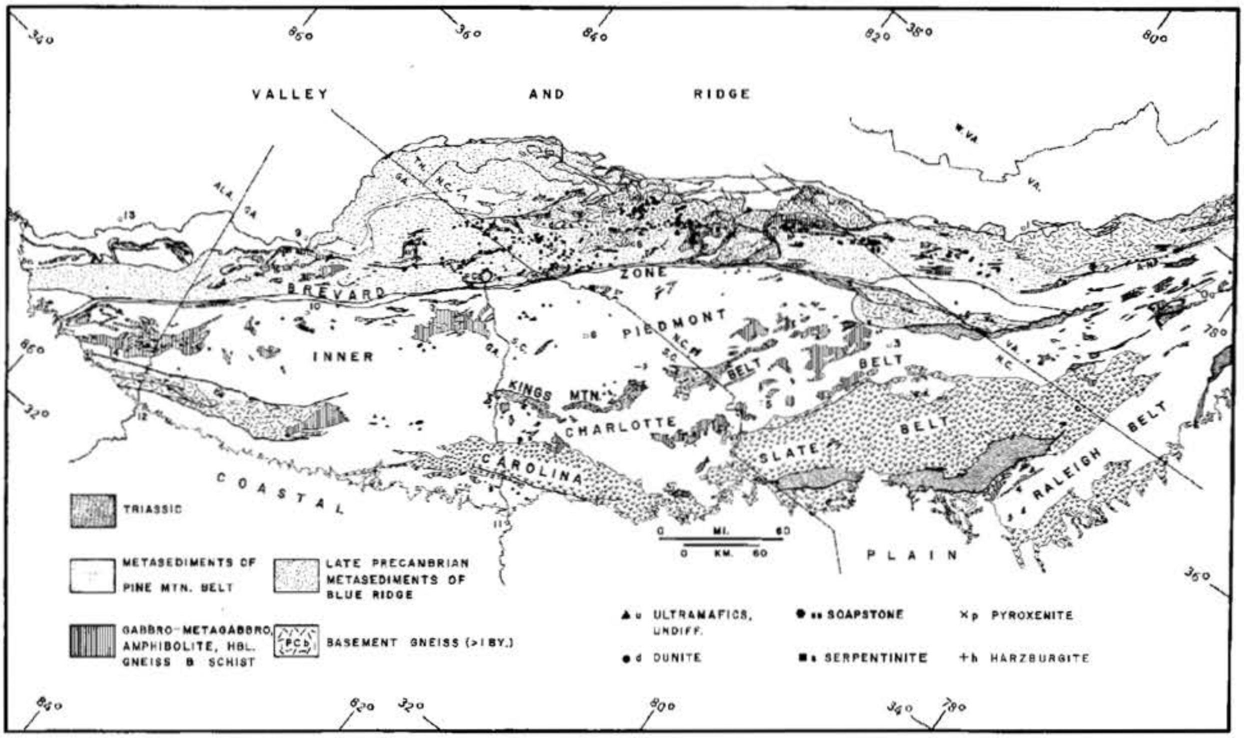

FIGURE 4. Geologic map showing the well-defined "chain" of ultramafic bodies in the Blue Ridge belt and the scattered ultramafic bodies in the Piedmont province (from Misra and Keller, 1978).

in the southern Appalachians was the upper mantle (Chidester and Cady, 1972; Rankin, 1975; Misra and Keller, 1978; Swanson, 1981).
The ultramafic bodies are believed to be fragments of the upper mantle that were "pinched off" during upwelling in a rift zone, and then tectonically "squirted" or "squeezed" into the overlying crust and sediments during eugeosynclinal deformation (Chidester and Cady, 1972; Rankin, 1975; Misra and Keller, 1978; Swanson, 1981).

The rift would form by the outward movement of upper mantle material, which would produce distension and "necking" of the crust. The upper mantle material would upwell in the rift, causing lateral downwarping and initiating the eugeosyncline (Chidester and Cady, 1972).

There seems to be some question whether the ultramafic bodies of the southern Appalachians were formed in rift zones within continental crust or in oceanic crust. According to Chidester and Cady (1972), the ophiolite complexes of the northern Appalachians were produced in an oceanic rift (ridge) system and the northern Appalachians eugeosyncline was underlain by oceanic (simatic) crust. However, they suggest that the ultramafic bodies in the southern Appalachians developed in a rift system within continental crust. Odom and Fullagar (1973), and Hatcher (1978) believe that the southern rift zone was floored by a small amount of oceanic crust that formed after rupture of the continental crust. Rankin (1975) suggested that even if oceanic crust had not formed within the rift zone, the continental crust would have been greatly thinned by crustal extension. The thinning would have promoted upwelling of upper mantle material and the eventual incorporation of ultramafic bodies into the eugeosyncline.

A common feature of the ultramafic bodies of the Blue Ridge belt is their close association with amphibolites (Misra and Keller, 1978).

These authors suggest, however, that this does not mean there is a definite genetic relationship between the two, particularly in terms of a common source material. According to them, basaltic lavas were erupted along the rift zone, became incorporated into the sedimentary sequence and later were metamorphosed to the amphibolite facies. The ultramafic bodies apparently became "associated" with the basaltic lavas when they were emplaced tectonically into the eugeosynclinal sedimentary sequence. Basaltic lavas are formed by the melting of material deeper in the mantle then the residual peridotite upper mantle layer, which is the source of alpine-type ultramafics (Chidester and Cady, 1972; Misra and Keller, 1978).

Most investigators consider alpine-type ultramafics to have been emplaced in the upper crust as solid bodies. To explain the problem of the upward transportation of a solid body, Misra and Keller (1978) suggested that at shallow levels ultramafic bodies move as fault-bounded slices and thrusts under tectonic stress gradients. The blocks or slices could move without internal flow, but the movement probably would be facilitated by serpentinization at the borders (Misra and Keller, 1978). Misra and Keller also suggested that the ultramafic bodies could move as diapirs if the pore pressure at the peridotite-wet sediment contact was equal to or exceeded the overburden pressure. According to Hatcher (1981), during compression, ultramafic bodies could be forced upwards as "watermelon seed" diapirs with the development of hydrated borders.

Several lines of evidence suggest that the ultramafic bodies in the Blue Ridge belt of the southern Appalachians were emplaced as "cold", solid bodies. They are: (1) a lack of thermal metamorphism at the contacts between the bodies and the enclosing rocks; (2) serpentinized and brecciated contacts; and (3) preferred orientation of recrystallized olivine that does not relate with regional patterns of deformation (Kingsbury and Heimlich, 1978; Misra and Keller, 1978).

Most researchers that have worked on the formation of ultramafic bodies believe that the peridotites were emplaced as fresh ultramafic material that later underwent partial hydrous alteration to serpentine (Kingsbury and Heimlich, 1978; Misra and Keller, 1978). Other investigators have suggested that most of the Appalachian ultramafic bodies were emplaced as solid serpentinite that was partially dehydrated during regional metamorphism (Carpenter and Phyfer, 1969). These authors propose that when the upper thermal stability limit of serpentine was exceeded, the serpentinites were dehydrated to olivine-rich rocks. If the thermal maximum (approximately 500°C) was not reached, the original mineral assemblage would remain (Carpenter and Phyfer, 1969).

Tectonic History of the Southern Appalachians

Late Precambrian rifting that eventually would from the Proto-Atlantic ocean marked the first phase in the development of the Appalachian orogen (Misra and Keller, 1978). Separation occurred 1200-1000 m.y. ago, along the old Grenville orogen (Odom and Fullagar, 1973), and a major water-filled graben system developed to the east of the present-day Blue Ridge Anticlinorium (Rankin, 1975). Basalts and sediments of the Ashe Formation were deposited in these water-filled basins (Hatcher, 1978). Ultramafic bodies were also being formed along the rift zone as upper mantle material upwelled along tensional features associated with rifting (Misra and Keller, 1978).

By Cambrian time, an island arc system had formed off the Blue Ridge province, in response to ocean plate subduction during the early stages of the closing of the Proto-Atlantic ocean. Most authors believe that the island arc system is the present-day inner Piedmont province, and they suggest that the island arc was the leading edge of the African plate (Figure 5) (Odom and Fullagar, 1973; Rankin, 1975).

The east-dipping subduction of the plate containing what is now the Blue Ridge, beneath the Piedmond island arc, resulted in (1) closing of the marginal sea; (2) convergence of the plates; and (3) the eventual collision in the middle Ordovician represented by the Taconic orogeny. The Brevard zone represents the suture along which the Blue Ridge and Piedmont province are connected (Figure 5) (Rankin, 1975). According to Odom and Fullagar (1973), solid ultramafic bodies were emplaced into the eugeosynclinal sedimentary material by squeezing and thrusting during the Taconic compression.

Following arc-craton collision during the Ordovician, a westward-dipping subduction zone developed along the east side of the arc-continent block, where oceanic crust of the African plate was subducted (Figure 5) (Odom and Fullagar, 1973). Metamorphism and deformation continued in the Blue Ridge belt until about 300 m.y. ago, when the continent-continent collision of North America and Africa occurred (Odom and Fullagar, 1973; Hatcher, 1978). In the Devonian, melting of peraluminous sedimentary rocks during metamorphism produced the fluids that were injected as pegmatite bodies of the type found within and around the margin of the Day Book ultramafic body (Rankin et al., 1973). Thus, the ultramafic bodies of the southern Appalachians apparently were emplaced during the Taconic orogeny, the dominant metamorphic event in the region, and the pegmatites were intruded during a second metamorphic event accompanying convergence of the African plate and the North American plate carrying Blue Ridge and Piedmont rocks.

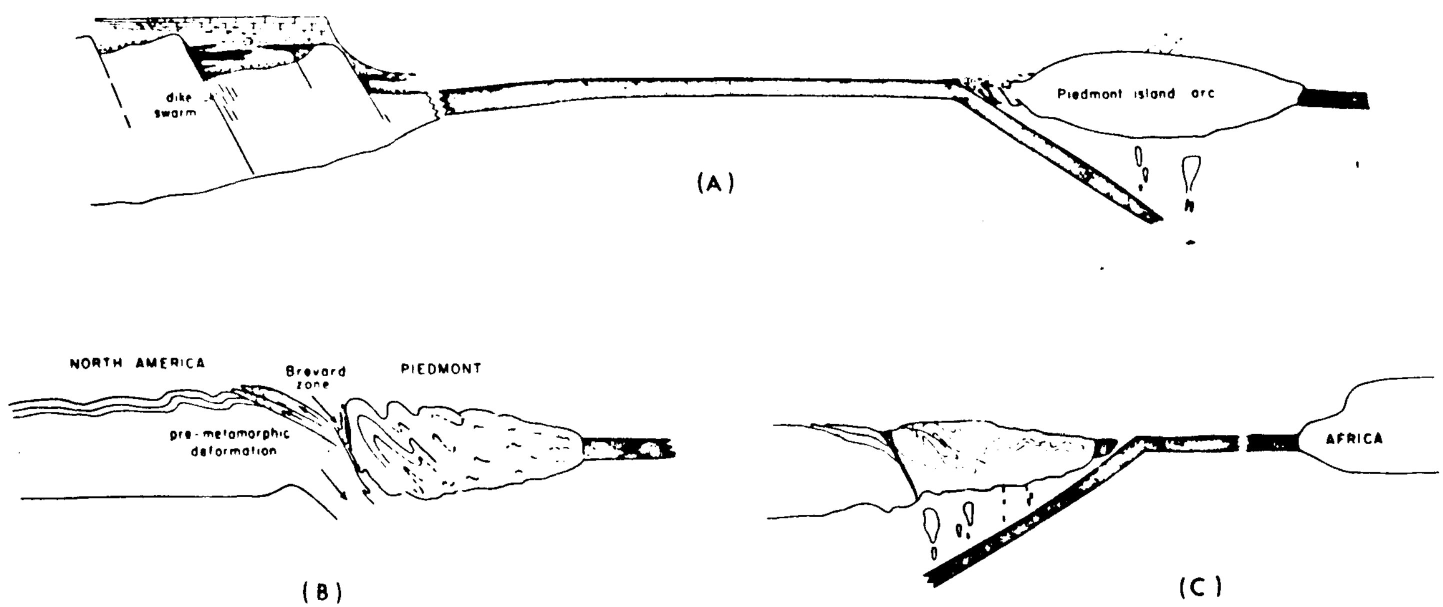

FIGURE 5. Diagram showing the Tectonic history and relationship between the Blue Ridge and the Piedmont provinces. A. Early Cambrian to Middle Ordovician. B. Late Ordovician collision between the Piedmont island arc and the North American continent. C. Westward-dipping subduction of the African plate beneath the North American plate (from Odom and Fullagar, 1973).

CHAPTER IV

PREVIOUS WORK AT THE DAY BOOK DUNITE BODY

The Day Book dunite body is typical of ultramafic intrusions found in the Blue Ridge belt, and aspects of its geology have been studied by a number of investigators. Hunter (1941) described the petrology and geology of the deposit, presented a map of the body, and estimated the economic potential of the deposit. Kulp and Brobst (1954) analyzed the vermiculite and concluded that it was formed by metasomatic alteration of phlogopite, related to the intrusion of granitic pegmatites along joints within and adjacent to the dunite body. Also, Kulp and Brobst presented a more detailed map of the deposit and described in detail the alteration and metamorphism noted around the margin of the body. Carpenter and Phyfer (1969) concluded that the absence of contact metamorphic affects around the margin of the dunite body, and the general lack of evidence of magmatic differentiation within the body, meant that the Day Book dunite was emplaced as a "cold" intrusion. They proposed further that the body was emplaced as a serpentinite and later dehydrated to olivine. Electron microprobe analyses by Carpenter and Phyfer (1975) revealed that the olivine had a fairly constant composition of $Fo_{92.4}$. This compositional homogeneity was further evidence for low temperature equilibrium crystallization (as from serpentine dehydration) rather than crystallization from a melt. McCormick (1975) identified chlorite associated with the chromite as kammererite, a chromian-bearing penninite. Carpenter and Fletcher (1979) analyzed the chromite, and noted that there is a slight compositional difference between disseminated and massive varieties.

Swanson (1981) published a comprehensive mineralogical and petrological study of the Day Book dunite body and the surrounding rocks. Mineral compositions were determined by microprobe analysis and mineral identifications were checked by x-ray diffraction. Swanson concluded that both disseminated and massive chromite compositions follow the trend defined by chromite found in "alpine-type" ultramafic bodies, having a constant Fe^{2+}/Mg ratio, a high Cr/Fe ratio and a high Cr/Al ratio. He also concluded that metamorphism of the dunite and of the country rock was contemporaneous with intrusion of the granite pegmatite. According to Swanson, the serpentinization was a late-stage alteration process unrelated to any metamorphic event observed in the country rock, and he suggested that clues to the mode of emplacement of the dunite body very likely would not be found in the recrystallized olivine petrofabric.

CHAPTER V

GEOLOGY OF THE DAY BOOK DUNITE AND ASSOCIATED ROCKS

The Day Book dunite is enclosed by metamorphic country rocks that include quartz-plagioclase-biotite gneiss and amphibolite. The amphibolite occurs as blocks and layers within the biotite gneiss, the dominant rock type in the area (Swanson, 1981). The biotite gneiss and amphibolites belong to the Ashe Formation and are late Precambrian in age (Butler, 1973). According to Rankin (1976), the Ashe Formation originally was a metagraywacke sequence with interbedded tholeiitic basalts. Although no pillow structures have been recognized in the lavas, the sequence of volcanic and sedimentary rocks probably represents a marine environment and it may have been associated with a rift system. Swanson (1981) believed that the relationship between the amphibolite blocks and the biotite gneiss is highly suggestive of a melange terrain.

According to Swanson (1981), the mineral assemblages in the country rocks correspond to the middle amphibolite facies (5-6Kb, 550-650^{o}C). The biotite gneiss is characterized by the mineral assemblage quartz + plagioclase + biotite + muscovite + garnet + staurolite + kyanite + chlorite. The amphibolite assemblage is hornblende + plagioclass + quartz $\pm$ garnet + sphene $\pm$ clinopyroxene (Swanson, 1981).

The dunite at the Day Book mine is in contact with biotite gneiss and amphibolite on three sides and on the fourth side it is in contact with a pegmatite intrusion (Figure 6) (Swanson, 1981). Other than small-scale metasomatic effects, the country rocks surrounding the dunite show no evidence of contact metamorphism and lack a thermal metamorphic

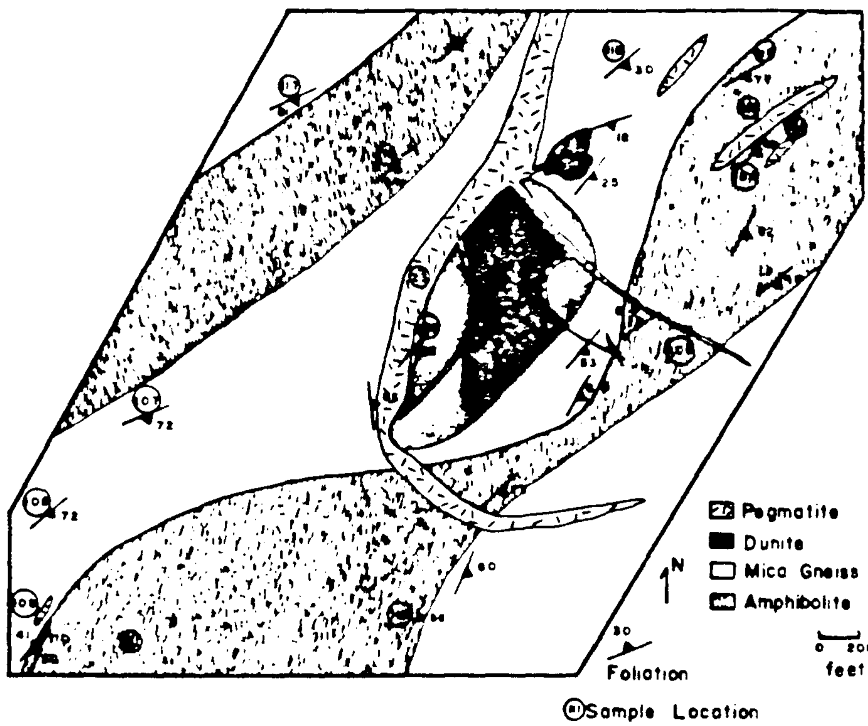

FIGURE 6. Geologic map of the Day Book dunite and country rocks (from Swanson, 1981).

aureole, which may mean that the dunite was emplaced "cold", as a solid body or as a "crystalline mush" (Carpenter and Phyfer, 1969; Swanson, 1981).

Quartz monzonite-granodiorite pegmatites intrude both the dunite and the country rock (Swanson, 1981). The pegmatites intruded along fractures and joints within the dunite and along the contact between the country rock and the dunite (Kulp and Brobst, 1954). Pegmatitic dikes within the country rock show two orientations. They generally are comformable to the regional metamorphic foliation, but some cross-cut the regional foliation (Swanson, 1981). Kulp and Brobst (1954) believe that the recurring association between large ultramafic bodies and pegmatites in the Spruce Pine district probably is related to structures within the ultramafic bodies. The pegmatitic fluids moved most easily along contacts between the dunite bodies and the country rock and along joints within the dunites. The pegmatites are believed to have intruded the country rocks and dunite during the Devonian Period, approximately 320-360 m.y. ago. (Butler, 1973; Rankin et al., 1973).

In the Spruce Pine district, the pegmatites appear to be restricted to areas where the metamorphic grade is staurolite or higher, which suggests that there may be a relationship between peak metamorphism and the formation of granitic magma (Rankin et al., 1973). Rankin et al. interpreted this to mean that the intrusion of the pegmatites also must have coincided with the peak of metamorphism. They concluded that the Spruce Pine plutonic group, including the pegmatites, are later than the dominant penetrative deformation of the Blue Ridge, but that they probably were coincident with a second deformation (i.e. Acadian orogeny). These workers also suggested that the formation of the pegmatites may be the result of the melting of peraluminous sedimentary rocks during high grade metamorphism.

The contacts between the dunite and the gneisses and pegmatites are outlined by a metasomatic reaction zone. Silica, aluminum, potassium and water moved from the pegmatite and/or the country rock into the dunite body, and magnesium from the dunite moved into the pegmatites and gneisses. This movement produced a series of mono-mineralic bands. From the dunite, outward, are zones of anthophyllite, talc, and finally vermiculite (Kulp and Brobst, 1954; Swanson, 1981).

Lithologically, the dunite is quite homogeneous, consisting of the primary minerals olivine, orthopyroxene and chromite, and secondary serpentine. The degree of serpentinization increases toward the contact with the country rocks and/or the pegmatites (Swanson, 1981).

Swanson noted that the only foliation observable within the dunite is the planar orientation of chromite layers and pods. Chromite layers range in thickness from 1 to 30cm. The chromite layers in some instances were folded isoclinally, with amplitudes of 5 to 20cm (Swanson, 1981). Swanson also observed that undisturbed pods generally are less than 20cm in diameter, but that blocks within the quarry contained chromite pods up to 3m in diameter.

Highly serpentinized shear fractures cut the dunite body, but they cannot be traced into the country rocks (Swanson, 1981). Swanson concluded, from cross-cutting relationships, that the shear fracturing occurred after the last metamorphic event in the region.

FIELD STUDIES

Samples for study were collected from the Day Book dunite mine in 1981 and 1983 by Dr. Douglas E. Pride. The samples were chosen to illustrate the spectrum of rocks and minerals present within the open pit at the time of collection.

LABORATORY STUDIES

Seven thin sections and four polished surfaces were prepared for study by the Ohio State University rock preparation laboratory. They were labelled DBD-1 - DBD-7, and DBD-1, DBD-4, DBD-6, and DBD-8, respectively.

A polarizing light microscope was used to identify mineral phases in thin section. The goals of the thin section studies were: (1) to identify all primary and secondary mineral phases, and (2) to determine the percentages, approximate grain sizes and the paragenetic relationships of the primary and secondary minerals. Study of recrystallization and deformational textures helped in sorting out primary versus secondary minerals, and in determining the percentage of the various phases. Mineral percentages were estimated using the A.G.I. Data Sheets 15.1 and 15.2 (A.G.I., 1982), and paragenetic sequences were determined by cross-cutting relationships and mineral replacement textures.

The opaque mineral phases within the Day Book samples were identified and studied using reflected light microscopy. Alteration and deformational and recrystallization textures were observed with reflected light. These studies helped in unravelling the paragenesis of the non-opaque as well as the opaque mineral phases.

Representative mineralogical and textural characteristics of the Day Book deposit, plus those unique features that were deemed important to understanding the origin and evaluation of the dunite body, were photographed. Examples were taken from both thin sections and polished surfaces.

THIN SECTION ANALYSIS

Primary and secondary phases were identified in thin section. Olivine (forsterite) enstatite, and chromite comprise the primary mineral assemblage. Secondary minerals include serpentine (chrysotile and antigorite), magnesite, chlorite, talc, magnetite, tremolite and anthophyllite.

Olivine is by far the dominant mineral, generally comprising more than 95 percent of all mineral phases. It occurs as small (.1-.5mm), equant, undeformed polygonal grains (Figure 7) and as large (.5-3mm) deformed anhedral grains frequently exhibiting undulatory extinction. The polygonal shape and straight-sided boundaries of the small grains indicate recrystallization, whereas the large deformed grains represent a relict texture (Ragan, 1969; Kingsbury and Heimlich, 1978; Swanson, 1981). In some samples, the recrystallized grains form a "mosaic" in which are found the strained olivine porphryoclasts. A gradational series exists between samples exhibiting complete recrystallization and those showing a large amount of strain (Figure 8).

Enstatite occurs as large, highly fractured and deformed, anhedral to subhedral grains, that range from 1 to 3mm in diameter (Figures 9 & 10). It usually comprises less than 3 percent of the mineral phases. Enstatite grains, like the olivine porphryoclasts, represent a relict phase and exhibit deformational textures. Unlike the small olivine grains, there is no evidence of recrystallization of enstatite. The grains commonly are bent, elongated and exhibit undulatory extinction (Figure 10).

Serpentine is the most common secondary mineral phase. It is present in every sample in amounts that vary from less than one percent (Sample DBD-1) to more than 95 percent (Samples DBD-4 and DBD-7). Two types of serpentine were identified, both of which are hydrous alteration products of olivine. Chrysotile occurs as fibrous fracture fillings cross-cutting the other minerals and forming "rinds" (borders) around olivine grains (Figure 11). Antigorite is present as irregular "patches" and flakes that replace olivine grains in highly serpentinized samples (e.g. DBD-4 and DBD-7). The olivine in these samples has been pseudomorphically replaced by serpentine, with rinds of fibrous chrysotile surrounding antigorite. Together they form a "mesh-like" texture (Figures 12 & 13). A second generation of serpentine, manifest as thick (2-3mm) fibrous chrysotile veins, cross-cuts the "mesh-like" texture in some samples. The veins also commonly contain a large amount of magnetite, which is present as (1) fine-grained masses within the veins and/or (2) as larger, subhedral grains that form borders to the veins (Figure 14).

Kammererite, a chromian-bearing chlorite, occurs as lath-shaped overgrowths with chromite and/or as an alteration of chromite (Figures 15 & 16). It is associated with both the massive and disseminated forms of chromite. Thus, the amount of kammererite varies directly with the amount of chromite. In sample DBD-1, which contains a massive lens of chromite, kammererite comprises 15 percent of all the mineral phases. Chlorite is present in veins as large euhedral grains associated with talc. It exhibits the polysynthetic twinning characteristic of clinochlore (Figure 17). (Kerr, 1977).

With one exception, talc and magnesite are minor phases and are confined to samples that are highly "veined" and metamorphosed. Talc occurs as large flakes and as fine-grained masses, and is associated with chlorite in veins that cross-cut the olivine. Magnesite is associated with massive chromite and occurs as microcrystalline masses and large crystals showing rhombohedral cleavage.

Tremolite and anthophyllite are present in the olivine matrix in small amounts, comprising less than 5 percent of the mineral phases. Tremolite occurs as blade-like crystals transversing the primary minerals (Figure 18), and anthophyllite is present as fibrous asbestiform masses, in sample DBD-5 (Figure 19).

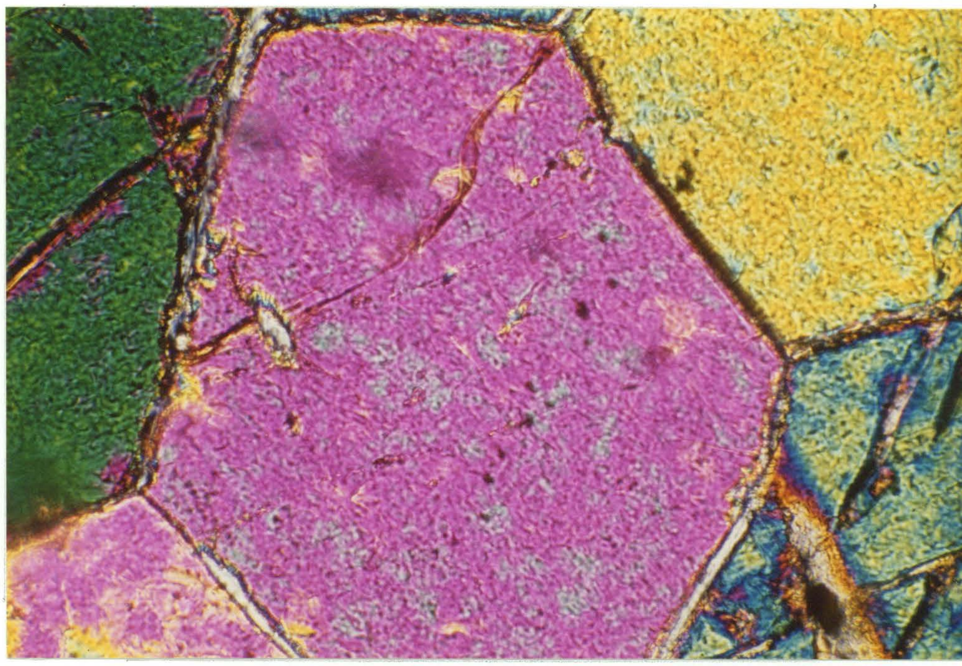

FIGURE 7. Thin section photomicrograph of sample DBD-2, showing equant, polygonal, recrystallized olivine grains meeting at 120° junctions (.1mm in diameter) (crossed nicols)(x160).

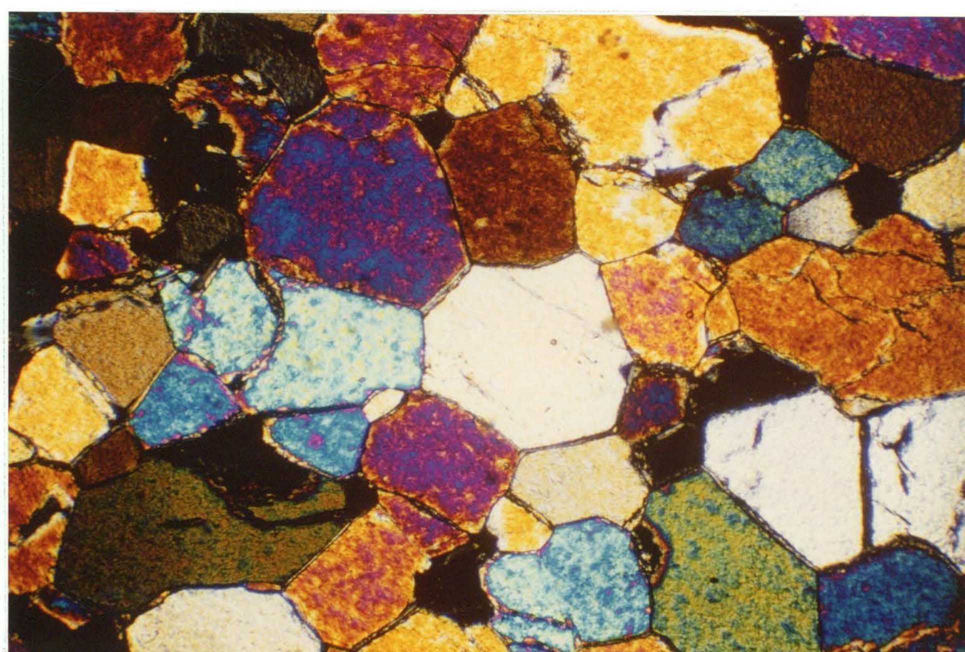

FIGURE 8. Thin section photomicrograph of sample DBD-1, showing recrystallized, partially recrystallized and relict olivine grains (crossed nicols)(x40).

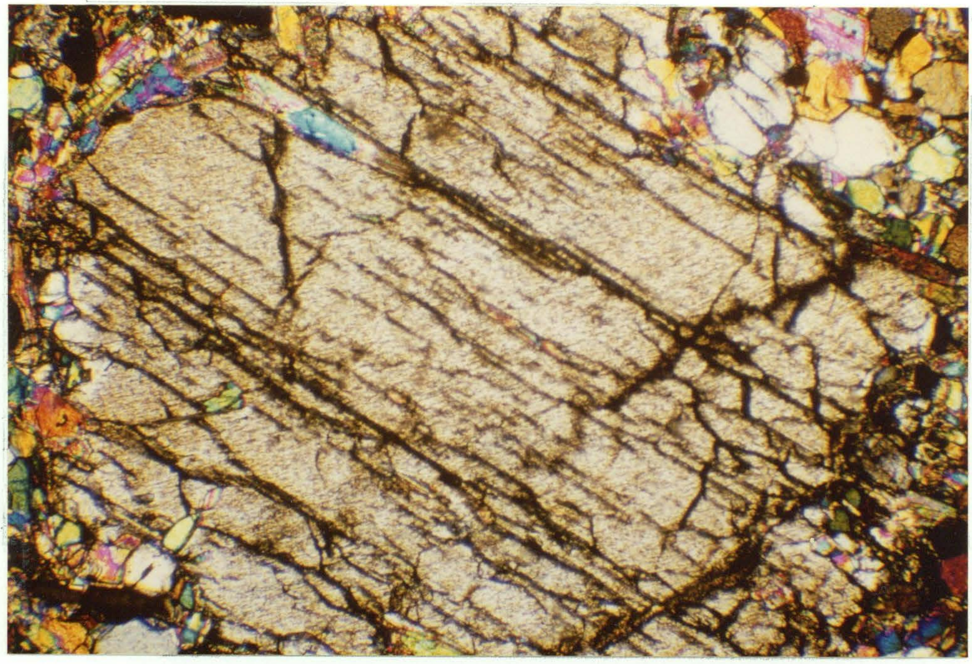

FIGURE 9. Thin section photomicrograph of sample DBD-3, showing a highly fractured, relict enstatite grains (3mm in diameter) (crossed nicols)(x40).

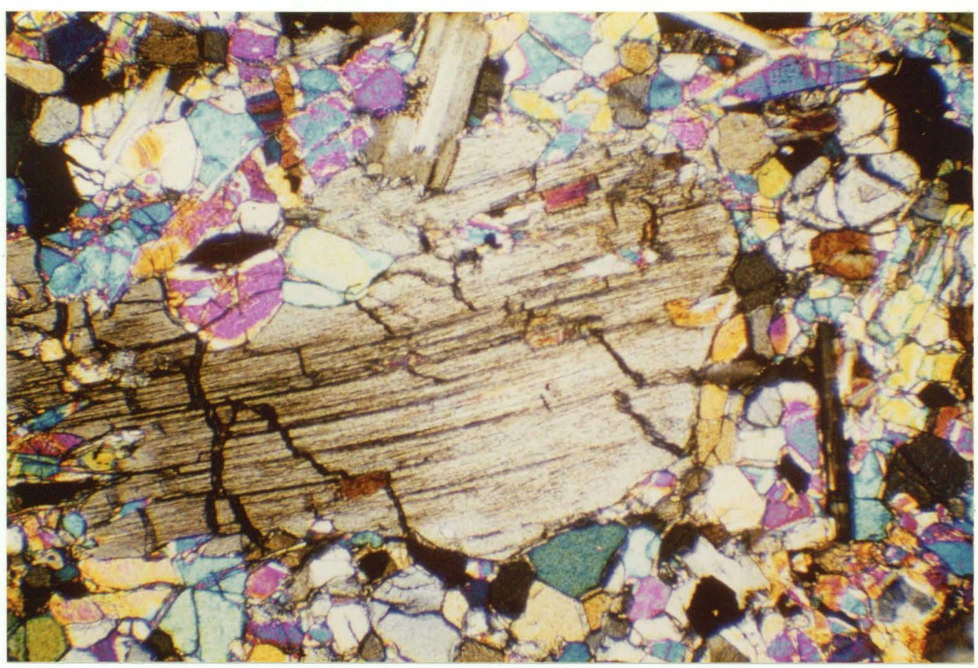

FIGURE 10. Thin section photomicrograph of sample DBD-3, showing a relict, enstatite grain, exhibiting undulatory extinction (crossed nicols)(x40).

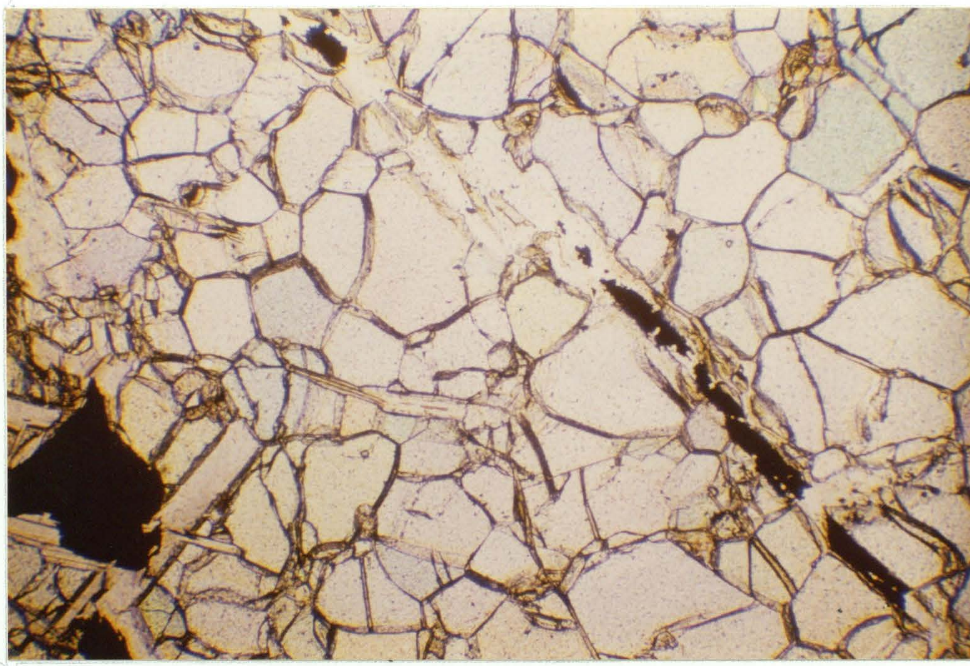

FIGURE 11. Thin section photomicrograph of sample DBD-3, showing a fracture filled with serpentine and associated magnetite, cross-cutting olivine (uncrossed nicols)(x40).

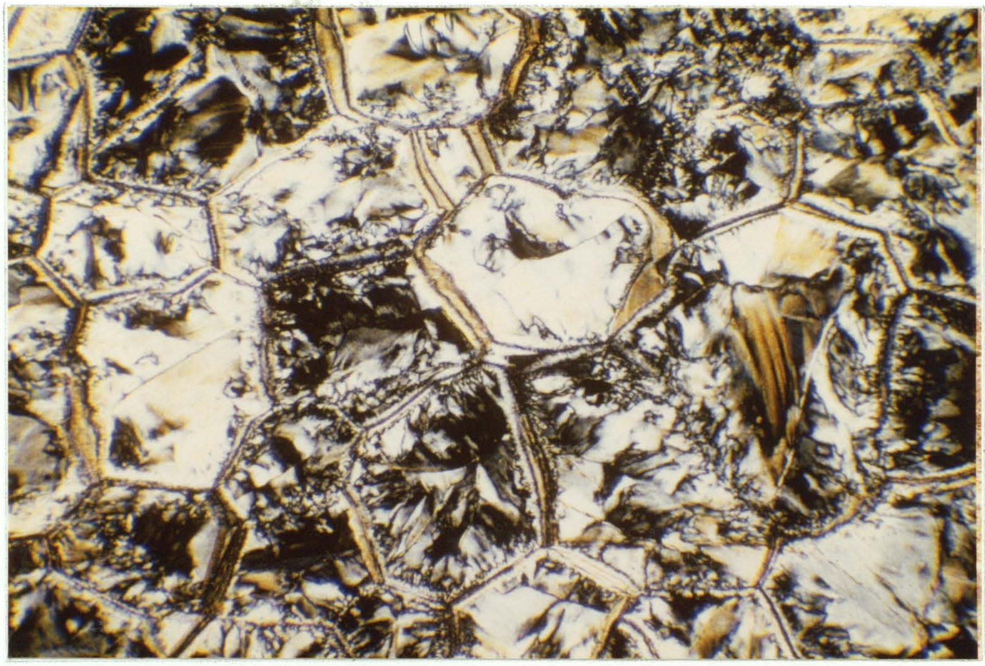

FIGURE 12. Thin section photomicrograph of sample DBD-4, showing pseudomorphic replacement of recrystallized olivine by chrysotile and antigorite (crossed nicols) (x40).

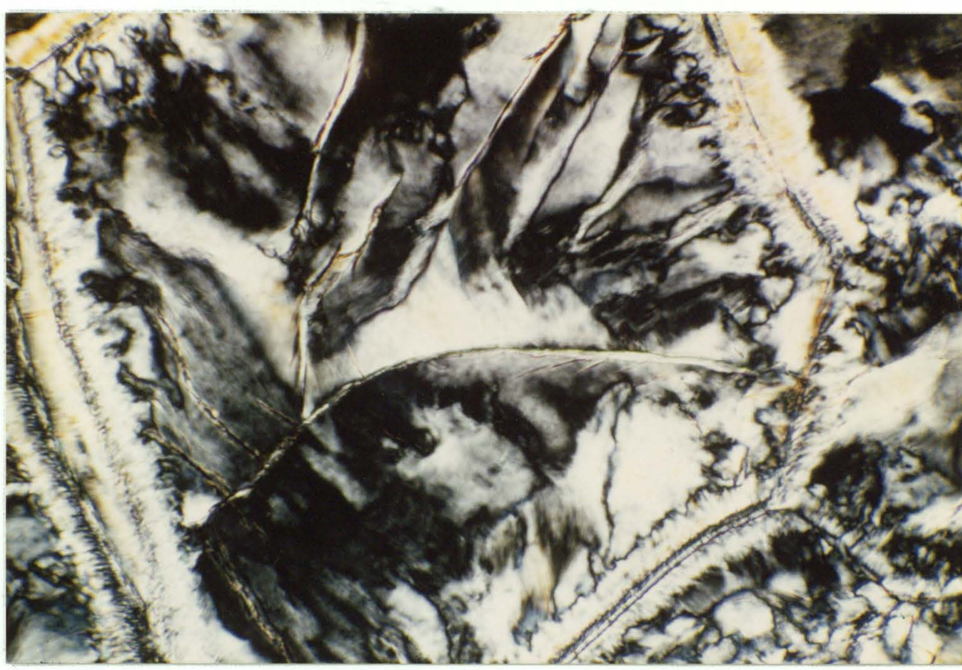

FIGURE 13. Thin section photomicrograph of sample DBD-4, showing pseudomorphic replacement of a recrystallized olivine grain by fibrous chrysotile (forming the border) and antigorite (irregular flakes in the interior) (crossed nicols) (x160).

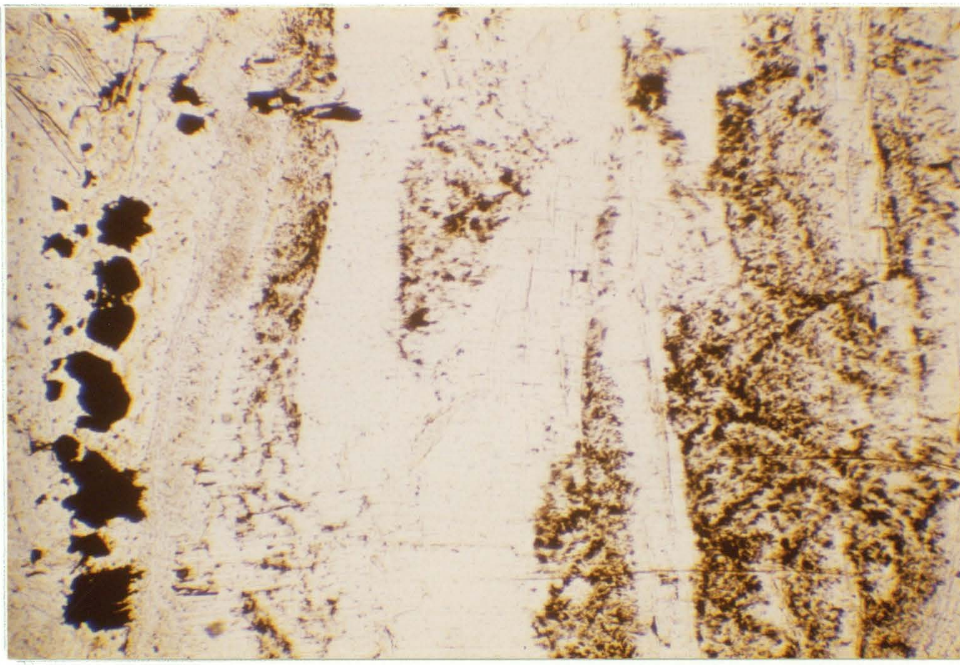

FIGURE 14. Thin section photomicrograph of sample DBD-7, showing a vein of fibrous chrysotile (3mm thick) filled with a fine-grained mass of magnetite and bordered by larger subhedral grains of magnetite (uncrossed nicols)(x160).

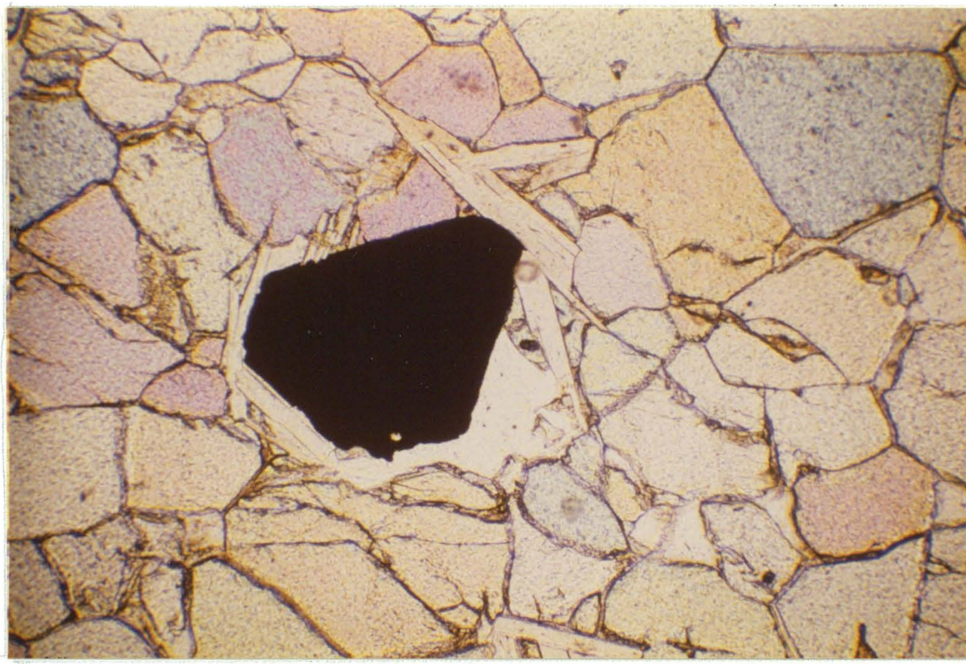

FIGURE 15. Thin section photomicrograph of sample DBD-1, showing a disseminated grain of chromite, surrounded by lath-shaped kammererite, in an olivine matrix (uncrossed nicols) (x 40).

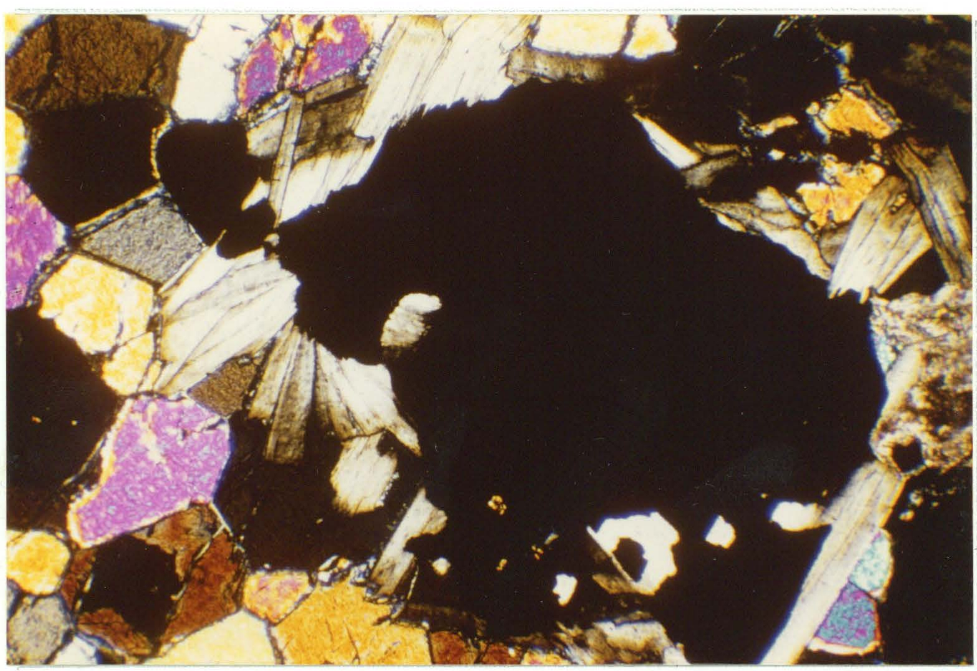

FIGURE 16. Thin section photomicrograph of sample DBD-1, showing a disseminated grain of chromite, surrounded by lath-shaped kammererite, in an olivine matrix (crossed nicols) (x 40).

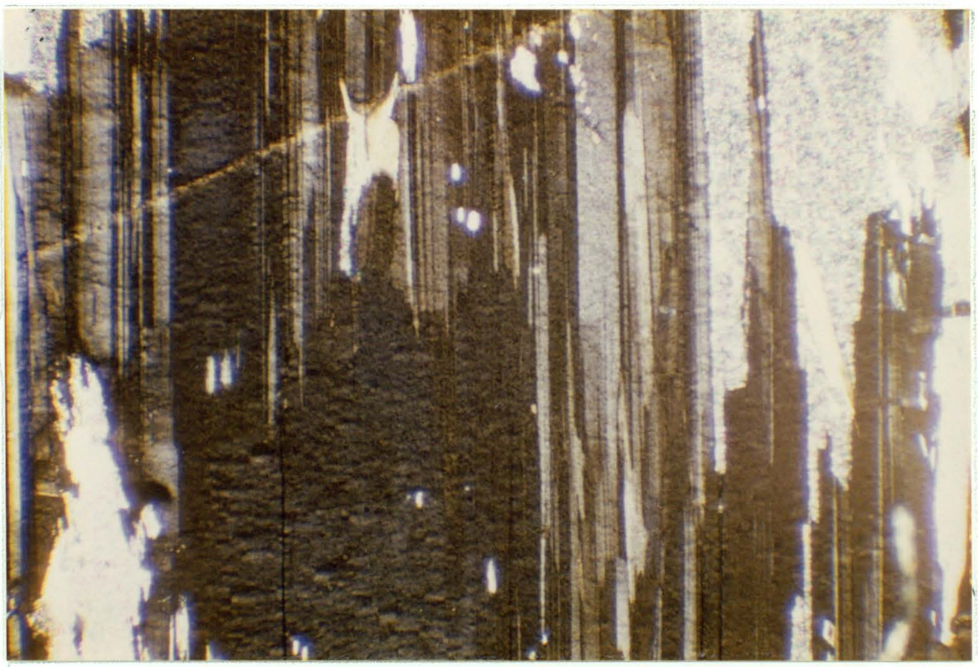

FIGURE 17. Thin section photomicrograph of sample DBD-2, showing a large chlorite grain (2mm wide), exhibiting polysynthetic twinning (crossed nicols)(x 40).

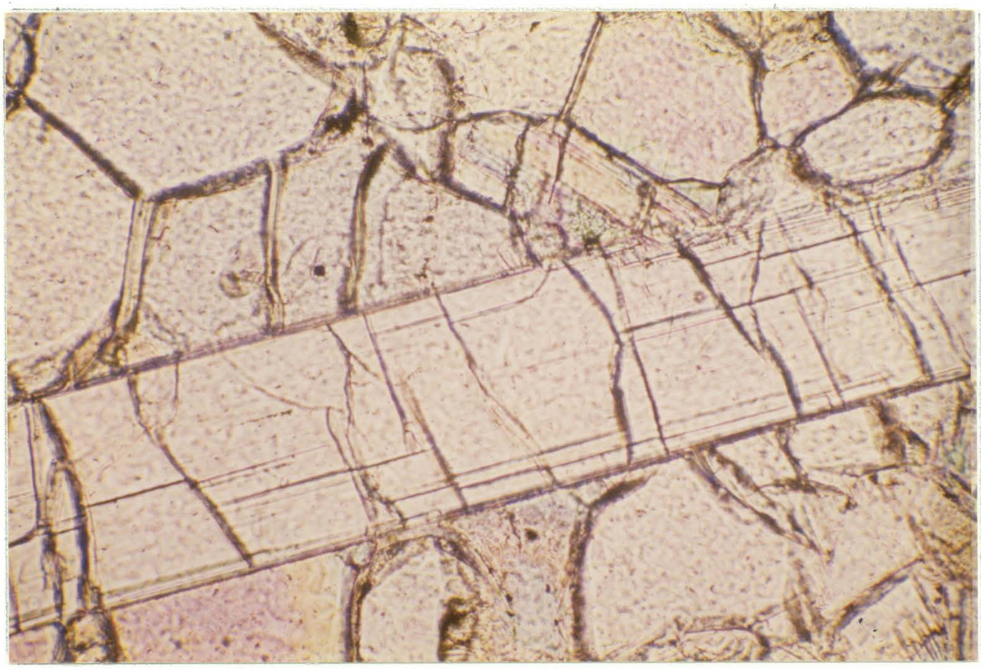

FIGURE 18. Thin section photomicrograph of sample DBD-3, showing a blade-like crystal of tremolite (uncrossed nicols) (x160).

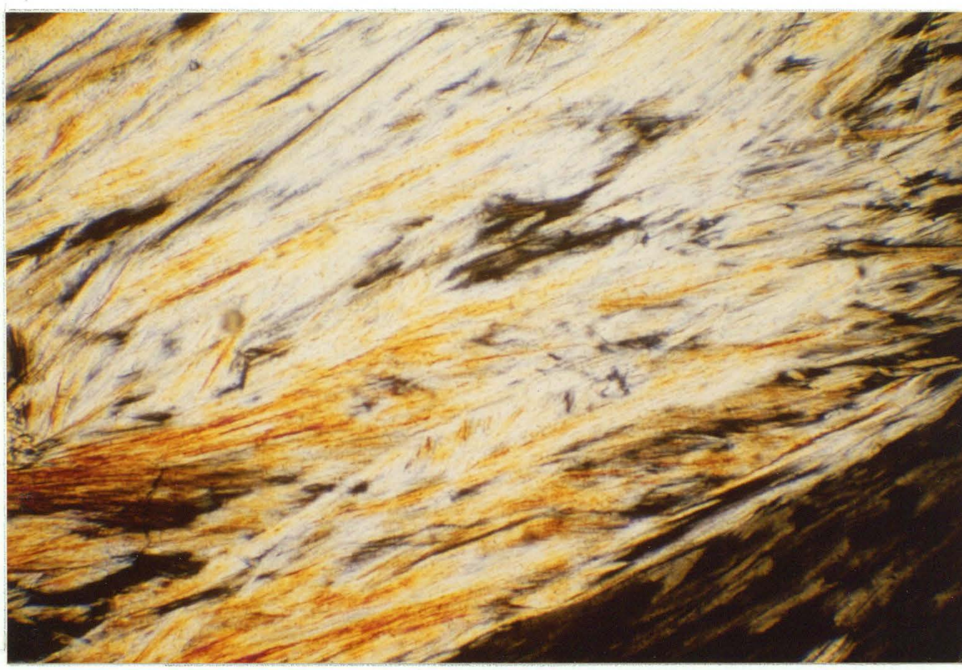

FIGURE 19. Thin section photomicrograph of sample DBD-5, showing a mass of asbestiform anthophyllite (crossed nicols) (x 40).

POLISHED SURFACE ANALYSIS

Chromite is by far the dominant opaque mineral phase, comprising at least 95 percent of the opaque minerals identified, and up to 25 percent of all mineral phases. It occurs in two forms: (1) as "massive" bands and blebs exhibiting cataclastic textures, and (2) as relatively undeformed, disseminated grains within a recrystallized olivine matrix.

The massive chromite occurs in rounded, subhedral grains and exhibits cataclastic textures. The grains appear brecciated and in some instances, elongated (Figure 20). Polished surfaces in which the chromite is most highly deformed also exhibit the most alteration of chromite to magnetite. The fracturing apparently increased the porosity and allowed serpentine to "embay" chromite, altering it to magnetite.

The disseminated chromite grains are relatively unstrained and exhibit little deformation. Some of the disseminated chromite apparently was "annealed" (recrystallized) at some time after crystallization. They now are straight-sided and exhibit polygonal outlines that meet at 120° junctions (Figures 21 & 22).

Both the massive and disseminated forms of chromite are associated with the mineral kammererite, a Cr-bearing penninite. This relationship is most evident in the disseminated form. Large lath-shaped grains of kammererite appear as overgrowths and/or alterations of the disseminated chromite (Figure 23).

Small amounts of magnetite are present as an alteration of chromite. Magnetite occurs as highly reflective fracture-fillings and as "rims" around massive chromite (Figures 24 & 25). The alteration of chromite to magnetite probably is related to serpentinization, where the content of chromium and magnesium decreases and iron increases at the borders and along cracks in chromite grains (Ramdohr, 1969; Bliss and MacLean, 1975). Sample DBD-8 is the only polished surface that contained significant magnetite, comprising approximately 5-10 percent of the opaque phases. In this sample, the contact between serpentinized olivine and a lens of massive chromite is the site of extensive alteration of chromite to magnetite. Grains of chromite apparently acted as a nucleus for the growth of relatively large masses of magnetite (Figure 26).

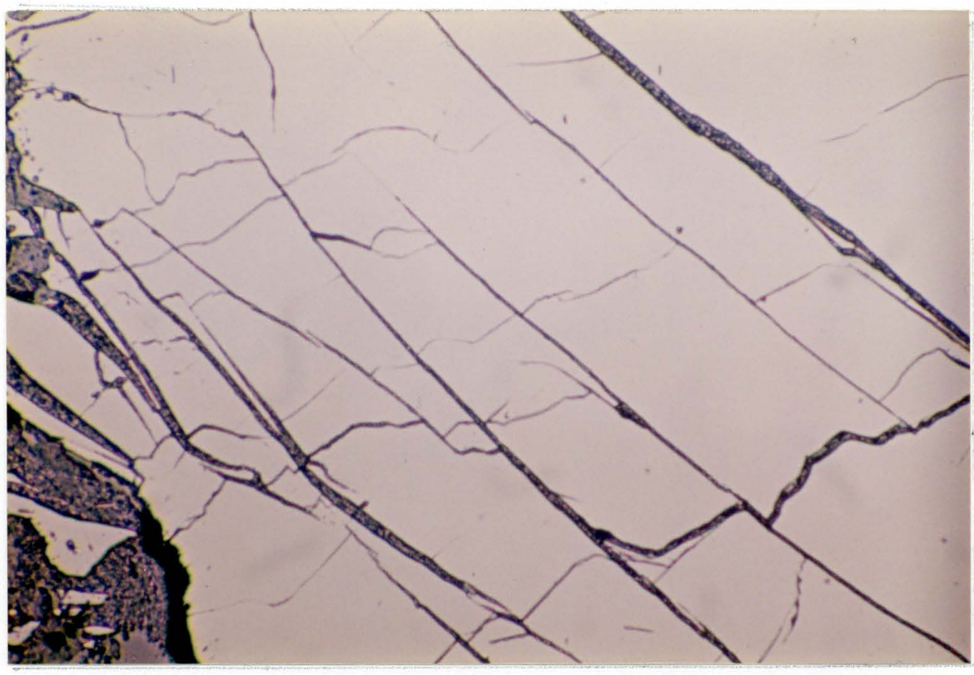

FIGURE 20. Polished surface photomicrograph of sample DBD-8, showing a grain of "massive" chromite exhibiting cataclastic texture (x100).

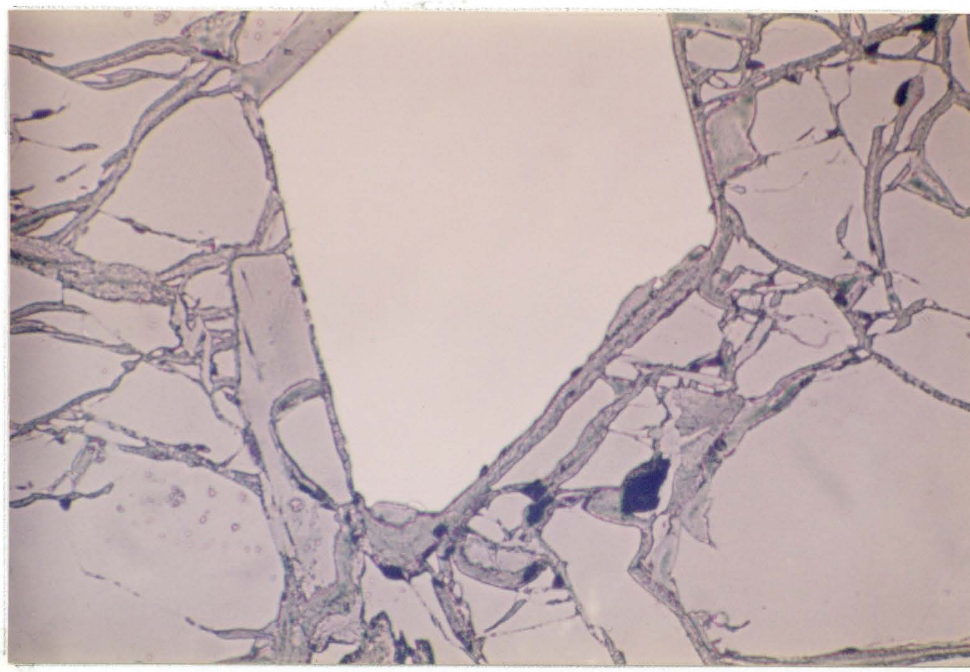

FIGURE 21. Polished surface photomicrograph of sample DBD-1, showing a straight-sided, recrystallized, disseminated chromite grain. (x 100).

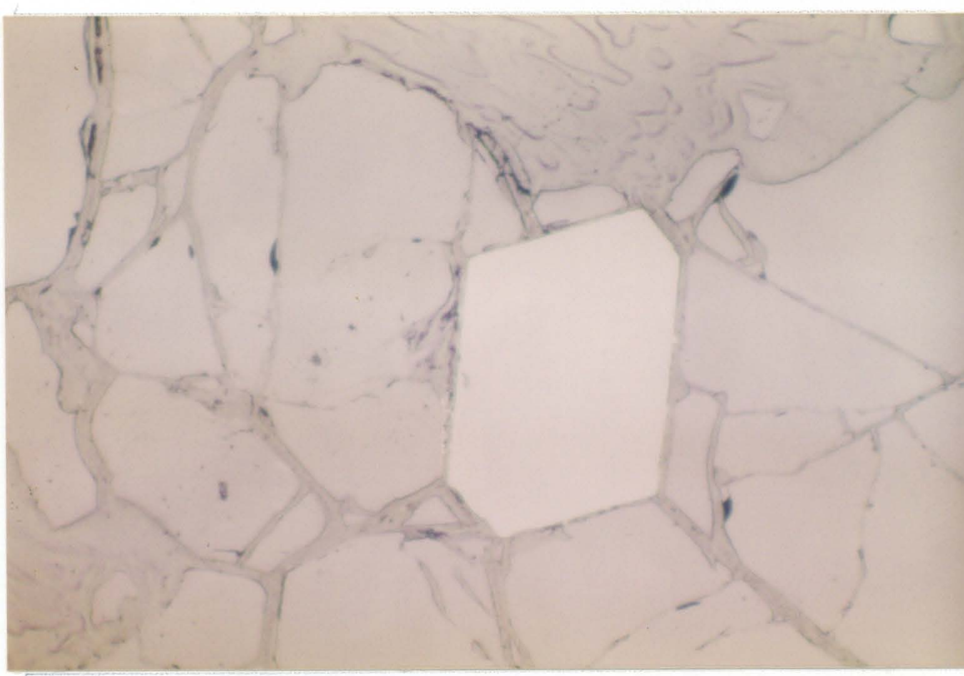

FIGURE 22. Polished surface photomicrograph of sample DBD-1, showing a recrystallized, disseminated chromite grain (x 100).

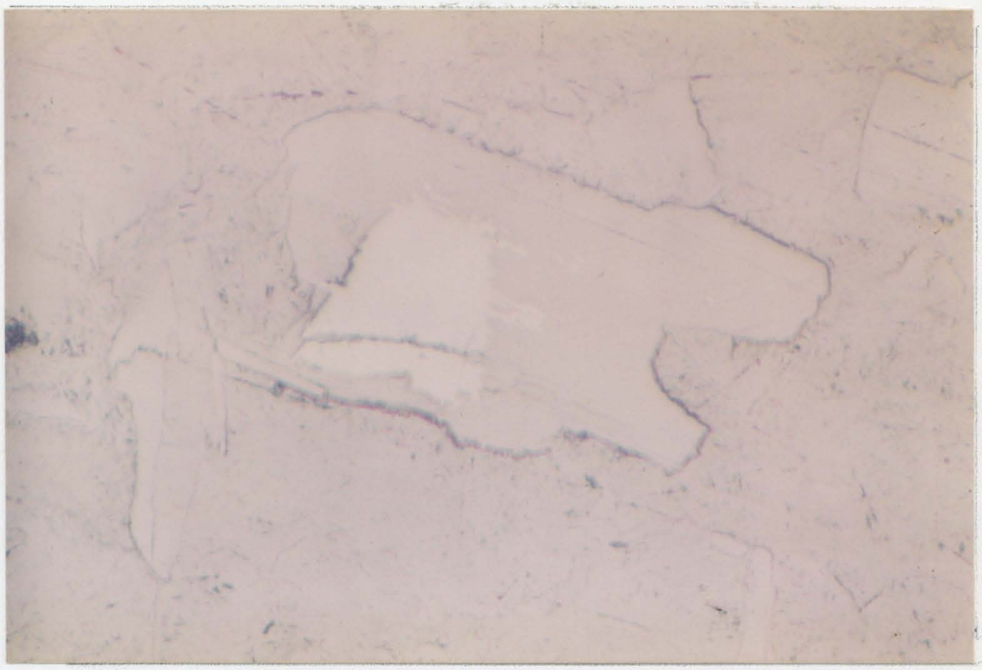

FIGURE 23. Polished surface photomicrograph of sample DBD-4, showing a disseminated chromite grain with an overgrowth of Kammererite. (x 100).

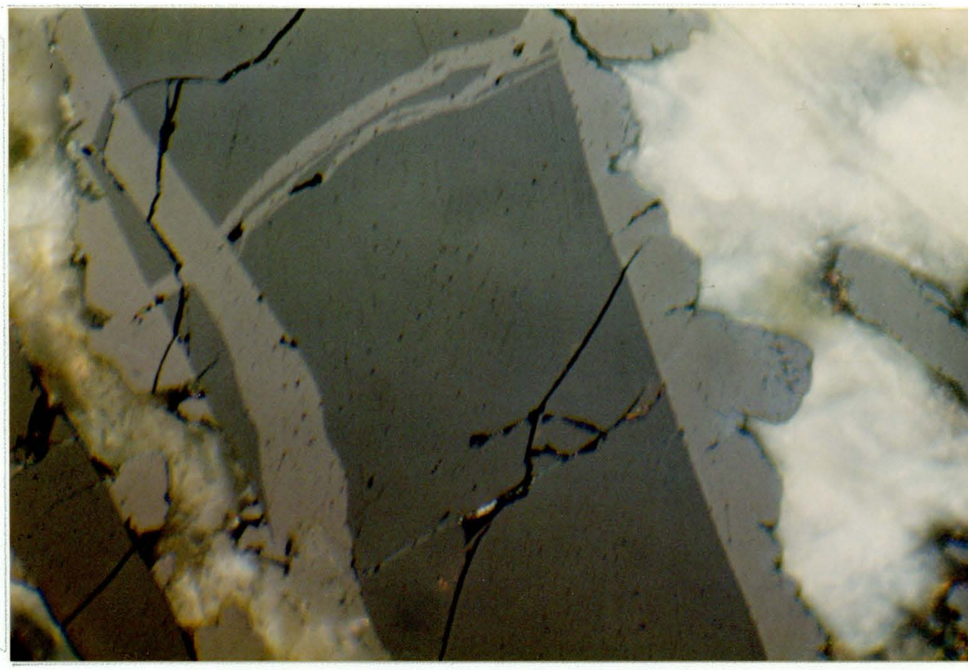

FIGURE 24. Polished surface photomicrograph of sample DBD-8, showing a fractured "massive" chromite grain (dark gray) with alteration to magnetite (light gray) (crossed nicols)(x 100).

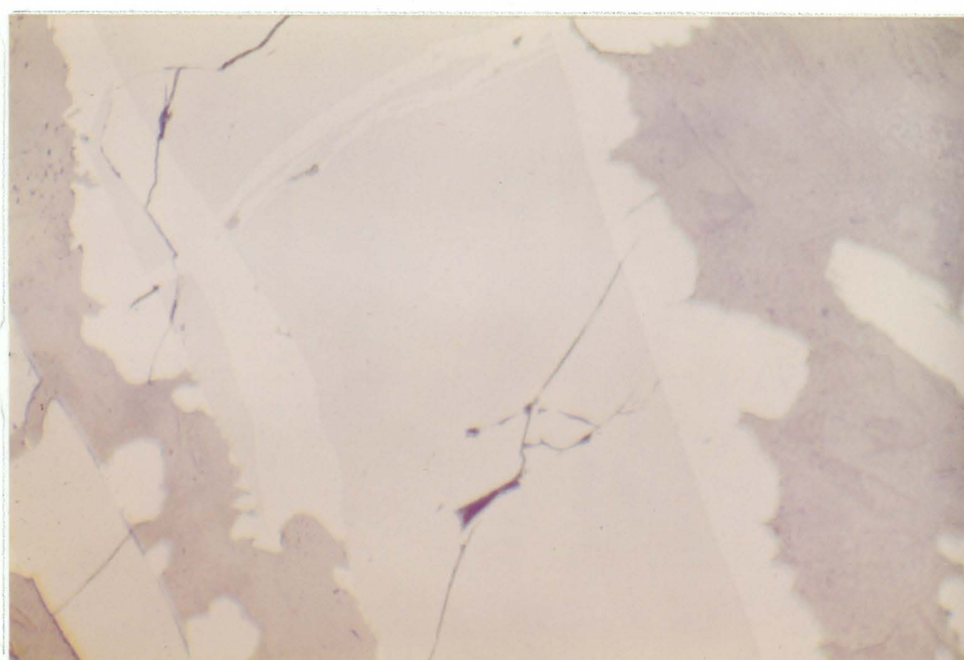

FIGURE 25. Polished surface photomicrograph of sample DBD-8, showing a "massive" chromite grain (gray) which has been altered to more highly reflective magnetite (white)(x 100).

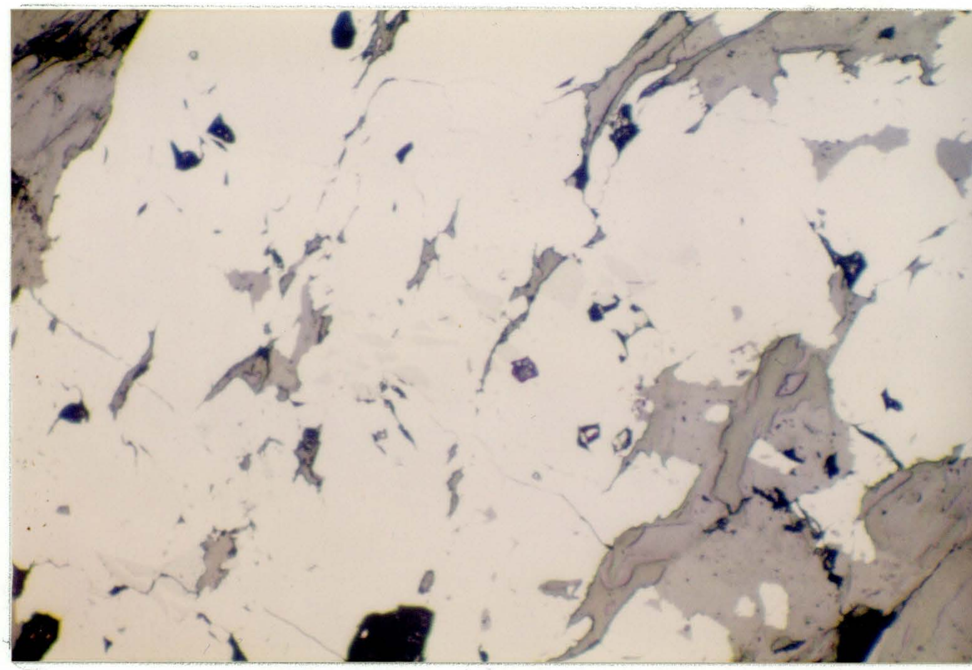

FIGURE 26. Polished surface photomicrograph of sample DBD-8, showing a large mass of magnetite with a small amount of chromite (gray) at the center(x100).

SUMMARY AND CONCLUSIONS

The mineral assemblage present in the Day Book dunite body, and its paragenesis, indicate that the dunite probably was emplaced as fresh ultramafic material that later underwent hydrous alteration during metamorphism and intrusion of the pegmatites.

Two generations of serpentine are evident in thin section. The first is represented by a "mesh-like" texture produced by serpentine pseudomorphically replacing (recrystallized) olivine grains. This period of serpentinization may have occurred during regional metamorphism, shortly after dunite emplacement, or as a result of intrusion of pegmatites during late-stage regional metamorphism. The paragenetic position of this generation of serpentine is difficult to discern, because other secondary minerals are absent from these samples. The pseudomorphic replacement of olivine by serpentine indicates that the dunite body was intruded as olivine that later partially hydrated to serpentine. This evidence argues against the conclusion by Carpenter and Phyfer (1969) that the ultramafic bodies of the southern Appalachians originally were emplaced as serpentine that later dehydrated, forming olivine.

The second generation of serpentine occurs as chrysotile fracture-fillings. This form clearly occurred after formation of the pseudomorphic serpentine and other secondary minerals. The second generation serpentine could have formed as a weathering product, as suggested by Swanson (1981), or as a late-stage, low-temperature hydrothermal alteration related to the intrusion of pegmatites.

The hydrothermal minerals anthophylite, tremolite, chlorite, magnesite, and talc originated during metamorphism, at the time the pegmatites of the region were emplaced. Swanson (1981) suggested that these secondary minerals were formed by H_2O-CO_2-rich fluids that evolved during crystallization of the pegmatites. Paragenetic relationships between these minerals are difficult to determine because few of the samples examined contain significant quantities of all of the phases. However, cross-cutting relationships and replacement textures indicate that anthophyolite, tremolite and magnesite formed first, followed by chlorite and talc.

There is some question as to where the olivine recrystallization occurred. The simplest explanation is that the olivine recrystallized after emplacement in the crust, during regional metamorphism. Petrofabric data from a number of other ultramafic bodies indicates, however, that the preferred orientation of olivine does not correspond with the regional metamorphic foliation. This has led many workers to conclude that the olivine petrofabric was developed by syntectonic recrystallization in the upper mantle, before emplacement in the crust (Sailor and Kuntz, 1973; Bluhm and Zimmerman, 1977; Kingsbury and Heimlich, 1977). This implies that the deformational events that took place in the crust were not of sufficient intensity to recrystallize the olivine grains. The large, anhedral relict olivine and enstatite grains apparently escaped recrystallization. It is possible that cataclastic textures and other brittle deformational features, such as those exhibited by massive chromite, were not developed in the mantle, but may have developed either during or after emplacement in the crust. In a similar manner, the fracturing that is superimposed on both the small recrystallized olivine and the large relict olivine grains may have occurred during emplacement into the upper crust.

A petrofabric analysis of the Day Book dunite, coupled with a detailed structural study of the country rocks, might help determine two important aspects of the geologic history of the ultramafic body.

(1) It could help determine if a preferred orientation of olivine exits, and by comparing these data with the regional metamorphic foliation, ascertain whether recrysallization took place in the mantle, during emplacement of the dunite body, and/or during regional metamorphism after emplacement.

(2) It also could help determine if the Day Book dunite and similar dunites of the southern Appalachians were emplaced as fresh ultramafic material or as serpentine that later dehydrated to olivine. The latter determination would be based on the assumption that serpentine would not dehydrate to olivine with a preferred orientation disconcordant to the regional metamorphic foliation.

It is not possible to determine exactly when recrystallization of the disseminated chromite occurred, but it is likely that the olivine and chromite recrystallized contemporaneously in the upper mantle. It would appear that a hard, brittle mineral such as chromite would recrystallize most easily under the high temperature and pressure conditions that exist in the upper mantle. Disseminated chromite grains surrounded by olivine would tend to recrystallize more readily than chromite in massive lenses and/or pods, which might partly explain why the massive chromite in the Day Book samples failed to recrystallize.

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Appendix A

POLISHED SURFACE REPORTS

OPAQUE PETROLOGY REPORT

Rock Type Dunite | Sample No. DBD-1

%	Primary Minerals
100	Chromite

%	Secondary Minerals

Comments:

"Massive" chromite occurs in rounded subhedral, moderately brecciated grains (.5-2mm).

Few "disseminated" grains are present, little or no alteration to magnetite.

Chromite comprises 30% of the polished surface.

OPAQUE PETROLOGY REPORT

Rock Type Dunite

Sample No. DBD-4

%	Primary Minerals
100	Chromite

%	Secondary Minerals

Comments:

Chromite occurs as disseminated grains, comprising less than 1% of the polished surface.

OPAQUE PETROLOGY REPORT

Rock Type Dunite

Sample No. DBD-6

%	Primary Minerals
99	Chromite

%	Secondary Minerals
1	Magnetite

Comments:

"Massive" chromite occurs in bleb 4mm in diameter, also several disseminated chromite grains are present.

Some alteration to magnetite along the borders of massive grains.

OPAQUE PETROLOGY REPORT

Rock Type Dunite

Sample No. DBD-8

%	Primary Minerals
95	Chromite

%	Secondary Minerals
5	Magnetite

Comments:

"Massive" chromite occurs as highly brecciated grains, highly altered to magnetite.

"Disseminated" chromite occurs as straight-sided, polygonal grains not exhibiting cataclastic texture or alteration to magnetite.

Magentite occurs as a highly reflective border alteration and filling fractures in massive chromite.

Appendix B

THIN SECTION REPORTS

PETROLOGY REPORT

Rock Type Dunite

Sample No. DBD-1

%	Primary Minerals
65	Olivine (Forsterite)
20	Chromite

%	Secondary Minerals
Tr*	Serpentine (Chrysotile)
14	Chlorite (Kammererite)
Tr*	Magnesite

Comments:

Olivine - Occurs as a mosaic of recrystallized, equant, polygonal grains (.1-.3mm), in which several large, deformed relict grains occur (1-4mm).

Kammererite - Occurs as lath-like epitaxial overgrowths of disseminated

Chromite is present in a 15mm wide "massive" band of rounded, subhedral, fractured grains, along with a few disseminated grains.

Serpentine (Chrysotile) forms "rinds" around olivine, and filling cross-cutting fractures.

*Present in recognizable amounts, but less than 1%.

PETROLOGY REPORT

Rock Type Dunite

Sample No. DBD-2

%	Primary Minerals
30	Olivine (Forsterite)
Tr*	Chromite

%	Secondary Minerals
1	Serpentine (Chrysotile)
Tr*	Chlorite (Kammererite)
8	Chlorite (Clinochlore?)
60	Talc
Tr*	Tremolite

Comments:

Olivine - Most of the grains are polygonal, recrystallized grains with straight or slightly curved grain boundaries (.2-.5mm). Several large, relict grains exhibiting undulatory extinction are present.

Chromite - Occurs as disseminated grains, with Kammererite overgrowths.

Talc and Chlorite are present in a vein 3cm. wide which cuts the dunite. Talc occurs as bent flakes surrounding chlorite, which occurs as large lath-shaped grains (.5-.3mm wide) exhibiting polysynthetic twinning.

Tremolite - Partially replaced by Talc.

Serpentine (Chrysotile) - Forms "rinds" around olivine grains.

*Present in recognizable amounts, but less than 1%.

PETROLOGY REPORT

Rock Type Dunite Sample No. DBD-3

%	Primary Minerals
88	Olivine (Forsterite)
3	Enstatite (Bronzite?)
1	Chromite

%	Secondary Minerals
Tr*	Serpentine (Chrysotile)
1	Chlorite (Kammererite)
5	Tremolite
Tr*	Talc
Tr*	Magnetite

Comments:

Enstatite - Occurs as large, fractured subhedral grains (1.33m-3mm in diameter), showing no evidence of recrystallization. Some are elongate and exhibit undulatory extinction.

Olivine, occurring as mostly small recrystallized, polygonal grains (.1-.5mm in diameter), meeting at 120° triple junctions. Many grains exhibit partially recrystallization. All the olivine grains are moderately fractured.

Chromite - Occurs as disseminated grains, bordered by Kammererite overgrowths.

Tremolite - Occurs as long, blade-like crystals cross-cutting olivine and enstatite.

Serpentine - Mostly Chrysotile - Forming rinds around olivine grains and filling fractures with magnetite.

*Present in recognizable amounts. but less than 1%.

PETROLOGY REPORT

Rock Type Dunite | Sample No. DBD-4

%	Primary Minerals
Tr*	Chromite

%	Secondary Minerals
1	Chlorite (Kammererite)
98	Serpentine
Tr*	Magnetite

Comments:

Serpentine pseudomorphically replacing olivine, forming a "mesh-like" texture, consisting of an outer rind of chrysotile and inner platy antigorite. Several large, relict olivine grains totally replaced by fibrous chrysotile (5mm in diameter).

Chromite occurs as disseminated grains, with overgrowths of Kammererite.

*Present in recognizable amounts, but less than 1%.

PETROLOGY REPORT

Rock Type Dunite — Sample No. DBD-5

%	Primary Minerals
78	Olivine (Forsterite)
Tr*	Chromite

%	Secondary Minerals
Tr*	Serpentine
1	Chlorite (Kammererite)
20	Anthophyllite
Tr*	Talc
Tr*	Tremolite

Comments:

Olivine - Occurs as large, relict, highly fractured, anhedral are present, little if any evidence of recrystallization. Large olivine grains exhibit undulatory extinction.

Asbestiform anthophyllite is present as highly fibrous masses of acicular grains; all having a parallel orientation.

Tremolite is present as blade-like crystals, cross-cutting olivine.

Kammererite - Occurs as overgrowths of disseminated chromite.

*Present in recognizable amounts, but less than 1%.

PETROLOGY REPORT

Rock Type Dunite   Sample No. DBD-6

%	Primary Minerals
92	Olivine (forsterite)

%	Secondary Minerals
1	Serpentine
Tr*	Chlorite (Kammererite)
1	Magnesite
2	Talc
Tr*	Magnetite

Comments:

Olivine - There is little evidence of recrystallization, most grains are large (.4-3mm), highly fractured, with curved grain boundaries and exhibiting undulatory extinction. Also elongate grains occur.

Chromite - Occurs as disseminated grains, surrounded by Kammererite.

Talc - Occurs with magnesite, surrounding chromite and filling fractures.

Magnesite - Occurs as large rhombohedral grains.

*Present in recognizable amounts, but less than 1%.

PETROLOGY REPORT

Rock Type Dunite   Sample No. DBD-7

%	Primary Minerals
Tr*	Chromite

%	Secondary Minerals
1	Chlorite (Kammererite)
98	Serpentine
Tr*	Magnetite

Comments:

Serpentine - Occurs in two forms: (1) chrysotile and antigorite pseudomorphically replacing olivine, retaining the polygoral outlines, resulting in a "mesh-like" texture, and (2) large cross-cutting vein occurrences of fibrous chrysotile, 2-3mm. thick with associated magnetite.

Chromite - Occurs as disseminated grains, surrounded and embayed by Kammererite.

Magnetite - Occurs as subhedral grains found on the borders of Chrysotile veins and smaller grained masses in the interior of the veins.

*Present in recognizable amounts, but less than 1%.